Bruce Fouke: Helping Search for Early Life

Bruce Fouke's career as a geologist was profoundly changed at the moment he first met internationally acclaimed microbiologist Carl Woese, whom he met in 1997. Having read that microbes may impact the most fundamental geochemical cycles within the world's oceans and continents, Fouke, a carbonate sedimentologist, was eager to meet microbiologists interested in collaborating in his studies of coral reefs and hot springs.

Bruce Fouke takes a sample at Mammoth Hot Springs in Yellowstone National Park, part of his work to study the process of microbial fossilization. Photo by Tom Murphy.

"I arrived on the Illinois campus in August of 1997 and met Carl that first week," remembers Fouke. "I shared my ideas with him about investigating the role of microbes in sedimentation and mineral precipitation. He responded, 'I like your thoughts, but I'm not going to introduce you to microbiologists. Instead, I will help you and your students to learn the basics of microbiology and complete the research yourselves.' Those words changed the course of my life."

Fouke apprenticed himself to Woese (who passed away December 30, 2012, at the age of 84) and to Abigail Salyers, another exceptionally accomplished microbiologist at Illinois. They helped him hire postdoctoral researchers with microbiology PhDs and to find some unoccupied lab space. Eventually Fouke received two important grants that helped him study the role of microbes in forming travertine deposits at Mammoth Hot Springs in Yellowstone National Park and to study emerging infectious diseases in coral reef ecosystems throughout the world. His growing success enabled Fouke to build a molecular geobiology laboratory in the Department of Geology, which he recently moved into the Institute for Genomic Biology.

Because Fouke's systems geobiology projects have depended on integrated metagenomics, proteomics and bioinformatics, he has been a regular client of the Roy J. Carver Biotechnology Center (CBC) at Illinois. Therefore, when Jonathan Sweedler stepped down as Director of the CBC after ten years, Fouke was a natural choice to replace him in November 2012. The CBC provides state-of-the-art, high-throughput sequencing, bioinformatics and biochemical analyses to more than 221 principal investigators on campus representing six colleges and 38 departments, as well as numerous off-campus projects. Fouke is happy to take on this new responsibility, with the interdisciplinary nature of the CBC strongly appealing to him.

"I have the kind of research program and personality that thrive on having friends and colleagues all across campus," he says. "The CBC gives me an opportunity to continue and even expand on that."

Today Fouke spends much of his time at the IGB. As a founding member of the IGB Biocomplexity theme, his work in better understanding the role of ancient microbes in sedimentation by applying metagenomic tools dovetails nicely with other researchers in that group looking for clues about early life. Fouke and his colleagues in that theme have just received a five-year, $8 million award from the NASA Astrobiology Institute (NAI). The grant will study the origin and evolution of life, with emphasis on the archaea. The University of Illinois is one of only five teams that were funded in the 2012 competition, which takes place every four years.

The Illinois NAI scientists believe that the early evolution of life took place in an extreme world that was very different from much of Earth today. It was a hostile world of hot temperatures, acidic conditions, and little to no oxygen. Researchers have wondered if perhaps environments with these harsh conditions would speed up evolution. This idea that the rate of evolution is not static is a relatively new concept, says Fouke. The Illinois NAI team will use their expertise on the microbial life of hot springs to shed light on the tempo and mode of microbial evolution in the face of steep environmental gradients. Their work will test the theory that early life may have evolved in places similar to hot springs, with their remarkably steep gradients of pH and temperature.

The NASA grant also will investigate Woese's theory that the earliest living cell, which had no translation machinery, may have contained some basic molecular components and a cell wall. This progenote, as Woese christened it, then evolved quickly into all three forms of life—archaea, bacteria and eukaryotes—almost simultaneously.

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"It's exciting that we can now conduct controlled experimentation on these incredibly fundamental questions that Carl initially proposed," says Fouke. "We're starting to see things we never guessed, suggesting some basic cell function and metabolic capabilities were first worked out in archaea and then transferred to bacteria and even eukaryotes. This is consistent with the notion that archaea, bacteria and eukaryotes evolved around the same time."

As part of the NASA grant Fouke also will lead a strong educational and public outreach program.

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This will include development of two new LAS Online courses, and a series of short science education videos ("SciFlix") in coordination with middle and high schools around the country and in Europe. The NAI team will also bring 100 middle school students and their teachers to observe first-hand the extreme thermal environments of Yellowstone National Park. Fouke will organize programs at the Illinois Osher Lifelong Learning Institute (OLLI) as well.

Fouke's research group is also using metagenome-enabled techniques to understand how coral are adapted to higher sea levels. As water temperatures rise and ice caps melt, coral are in danger of "drowning;" they will be too far from the surface for the algae that live in their tissue to photosynthesize. But Fouke has found that when the temperature rises, coral express different classes of proteins to help their skeletons grow faster, raising them close enough to the water surface that sunlight can reach them.

This is not the first time coral have had to adapt like this, Fouke points out. It's a crisis they've had to live through before. One of the first multi-cell eukaryotes with a skeleton (542 million years before present) was closely related to corals. Over this long period of time, sea surface temperatures reached significantly higher levels than they are on the modern day Earth.

However, while corals may be able to adapt to rising temperatures and sea levels, they are also struggling with new physical, chemical and biological threats created by human activity. For example, Fouke is looking at how corals respond to increasing coral disease by examining gene expression within a holistic geobiological context.

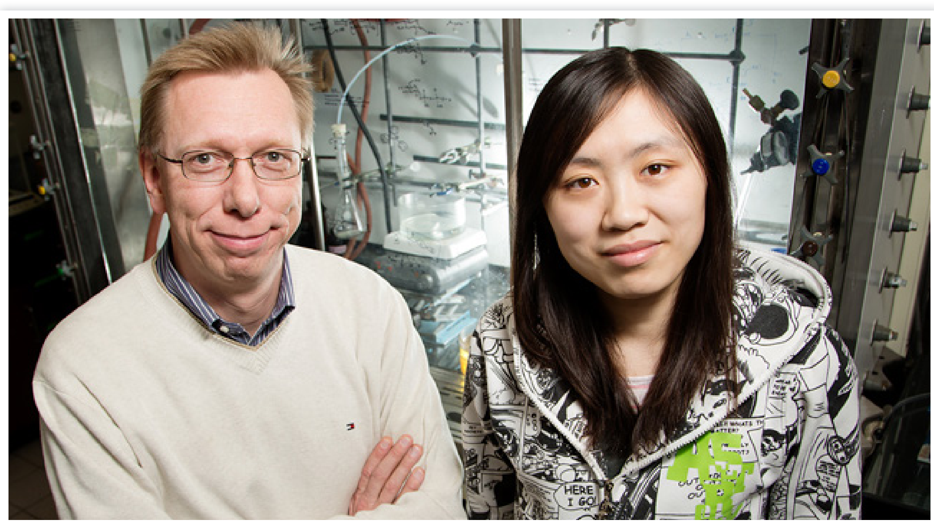
Yet another outlet for the Fouke lab group in genomics and sedimentation is the study of the history of ancient Roman aqueducts. The aqueducts, with their regular flow of spring water from the Italian Apennines, provided a highly controlled environment in which travertine rock deposition took place. In fact, travertine deposition reached four meters in thickness in some aqueducts, and provided a prized source for high-quality travertine in Roman temples and monuments. Using analyses they developed to study hot spring travertine deposition in Yellowstone, the Fouke lab group has been able to reconstruct the timing, temperature, chemistry, flow and microbiological composition of the ancient aqueduct waters from the aqueduct travertine deposits.

For example, archaeologists had theorized that the aqueducts fell into disuse when the Ostrogoths besieged Rome in 537 A.D. The Fouke lab's integrated use of geological, chemical and microbiological analyses indicates that water flowed in the aqueducts until as late as 950 A.D. "We may have upset a few archaeologists with our findings," he acknowledges, smiling.

But people tend to find it hard to stay upset with Fouke, whose sunny demeanor and outsize personality make him well known across campus. Those traits, plus his enthusiasm for interdisciplinary work, make him welcome in the many fields he has ventured into. ■

Research

Study: Odd Biochemistry Yields Lethal Bacterial Protein



›› Chemistry professor and IGB faculty Wilfred van der Donk, left, and graduate student Weixin Tang determined the unusual structure of a bacterial toxin.

While working out the structure of a cell-killing protein produced by some strains of the bacterium *Enterococcus faecalis*, researchers stumbled on a bit of unusual biochemistry. They found that a single enzyme helps form distinctly different, three-dimensional ring structures in the protein, one of which had never been observed before.

The new findings, reported in *Nature Chemical Biology*, should help scientists find new ways to target the enterococcal cytolysin protein, a "virulence factor that is associated with acute infection in humans," said University of Illinois chemistry and Institute for Genomic Biology professor Wilfred van der Donk, who conducted the study with graduate student Weixin Tang.

Enterococcus faecalis (EN-ter-oh-cock-us faye-KAY-liss) is a normal microbial inhabitant of the gastrointestinal tracts of humans and other mammals and generally does not harm its host. Some virulent strains, however, produce cytolysin (sigh-toe-LIE-sin), a protein that, once assembled, attacks other microbes and kills mammalian cells.

"The cytolysin protein made by *Enterococcus faecalis* consists of two compounds that have no activity by themselves but when combined kill human cells," van der Donk said. "We know from epidemiological studies that if you are infected with a strain of *E. faecalis* that has the genes to make cytolysin, you have a significantly higher chance of dying from your infection." *E. faecalis* contributes to root canal infections, urinary tract infections, endocarditis, meningitis, bacteremia and other infections.

Enterococcal cytolysin belongs to a class of antibiotic proteins, called lantibiotics, which have two or more sulfur-containing ring structures. Scientists had been unable to determine the three-dimensional structure of this cytolysin because the bacterium produces it at very low concentrations. Another problem that has stymied researchers is that the two protein components of cytolysin tend